EUV Interference Lithography with a Gas Discharge Source

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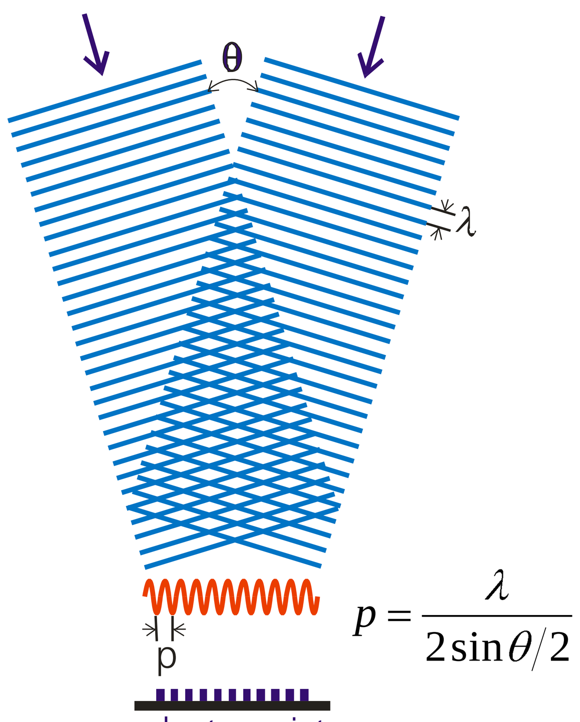
In this work the feasibility of using a Talbot self-imaging effect for EUV interference lithography with laboratory gas-discharge sources is studied. Analytical modeling together with ray-tracing simulations are employed to formulate the requirements to emission parameters. Emission of gas discharge source was optimised to achieve highest possible intensity within 3.2% bandwidth. Free standing thin Nb membranes for necessary transmission masks were manufactured with areas exceeding 1 mm^2 and patterned with e-beam lithography.
The obtained experimental and analytical results show that achromatic Talbot interference scheme allows reduction of a period of structures from mask to wafer and can be efficiently used for EUV-IL with an incoherent source, especially for structures with critical dimensions in sub-50 nm range.

EUV Interference Lithography



$$p = \frac{\lambda}{2\sin\theta/2}$$

- Large-area periodic structures
- Large depth of focus
- Requires a coherent light
- Low cost – no complicated and expensive optics
- Ultimate resolution for the wavelength (~λ/4) - e.g. 50 nm features with 193 nm light

EUV: λ = 11 nm → feature size: ~3 nm

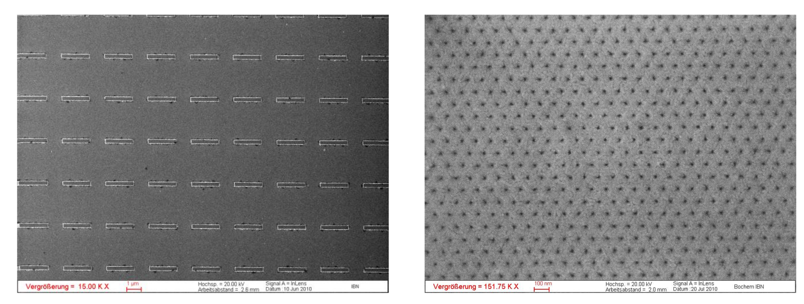
Dense patterns with half-pitch down to 11 nm are already demonstrated with EUV-IL using synchrotron radiation

Transmission masks manufacturing

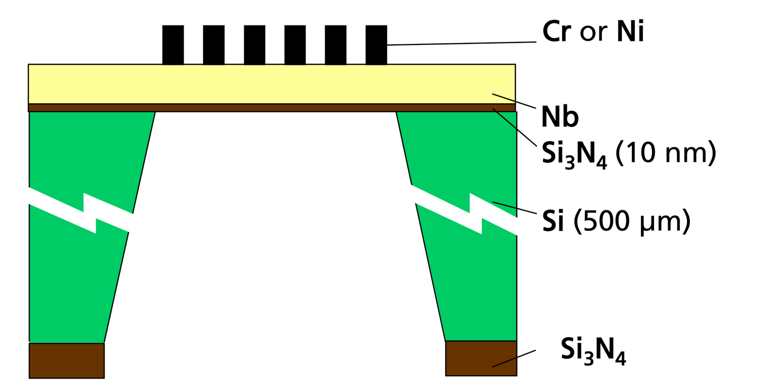
SiN_x- based masks can no longer be used at 11 nm – below Si L-edge!

Niobium is a suitable substitution for silicon nitride as a support membrane @ 11 nm:

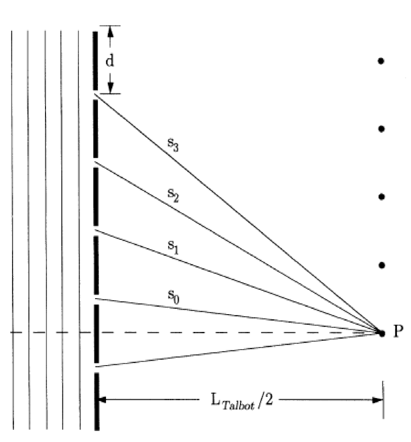
- Niobium with a thickness of 100 nm has a sufficient transmission of 65% at 11 nm
- Niobium as an built-in filter for wavelength > 18 nm
- Mechanically stable, used in MEMS technology



Nanoantenna and pinhole arrays with structure sizes down to 20 nm



Achromatic Talbot effect

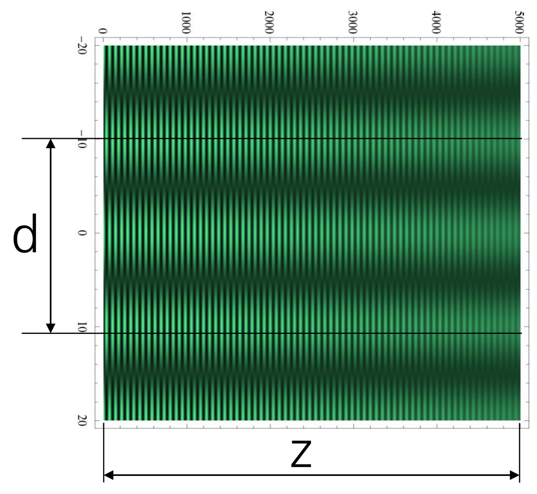


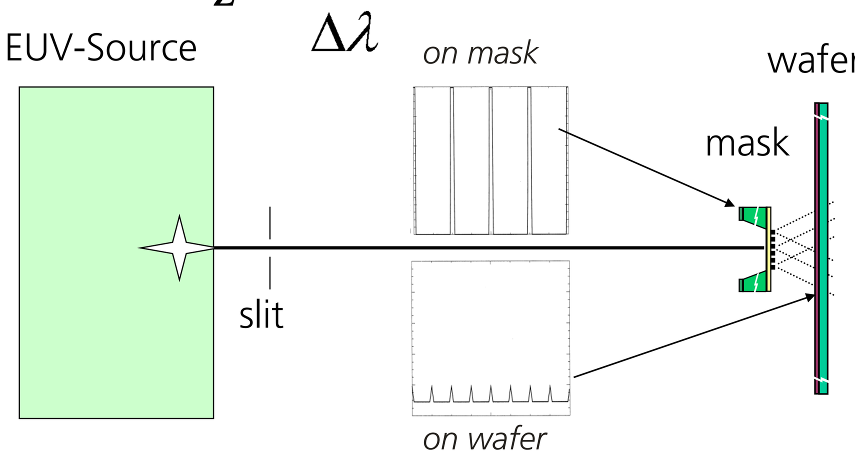
Self images of the grating at distances proportional to Talbot distance

$$L_{Talbot} = \frac{2d^2}{\lambda}$$

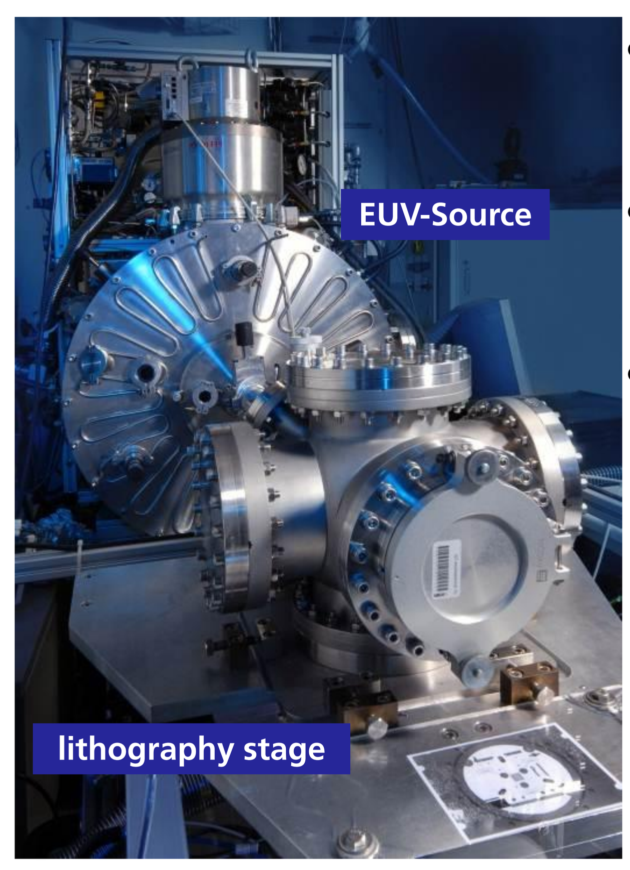
For not perfectly monochromatic light Talbot self images mix and form a stationary image with half of the grating period at a distance *z* (Δλ is a bandwidth of the source).

$$z = \frac{2d^2}{\Delta\lambda}$$

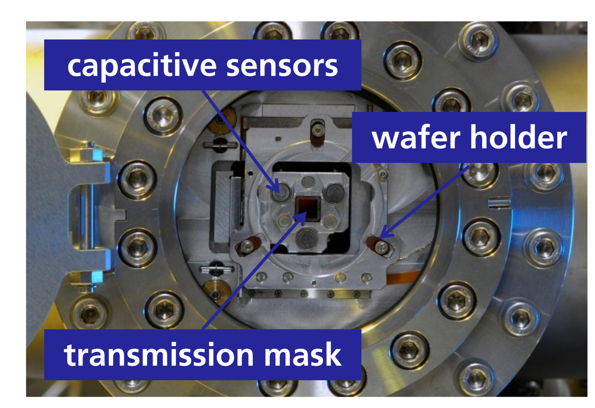




Illumination setup



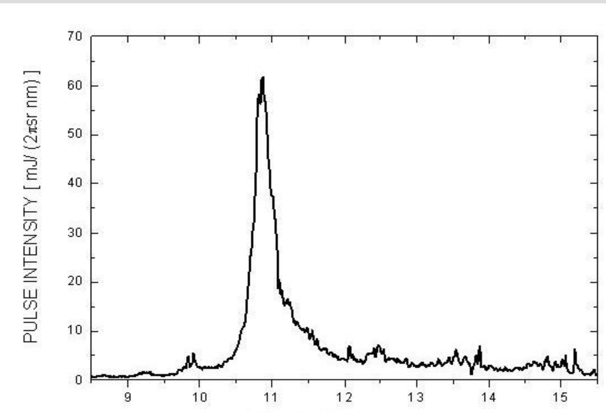
- Wafer-mask distance and tilt control with 10 nm precision - *necessary for Talbot lithography*
- Compact and rigid to minimise influence of vibrations - *critical for targeted sub-20 nm structures*
- Minimum optical components to reduce losses - *increasing of the throughput*

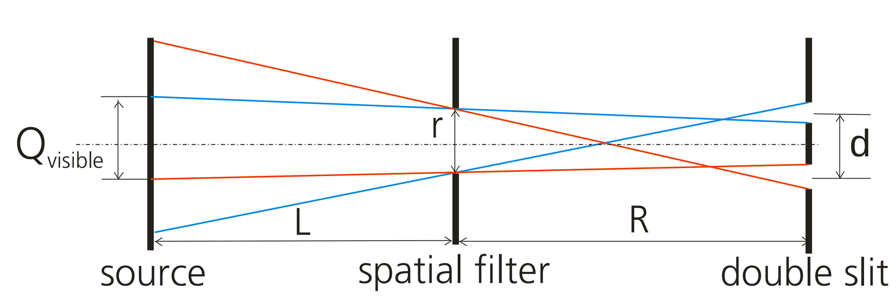


Proof-of principle setup for illumination of 2" wafers

Coherence with EUV gas discharge source

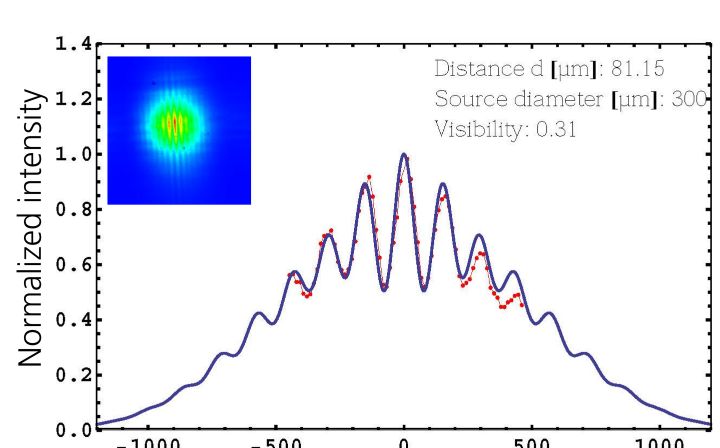
- Spot size / plasma diameter: 150-350 µm
- Optimized bandwidth @ 10.9 nm: 3.2 %
- Emission @10.9 nm (3.2 % b.w.): 20 mJ/(2πsr)
- Resist exposure times below 30 seconds

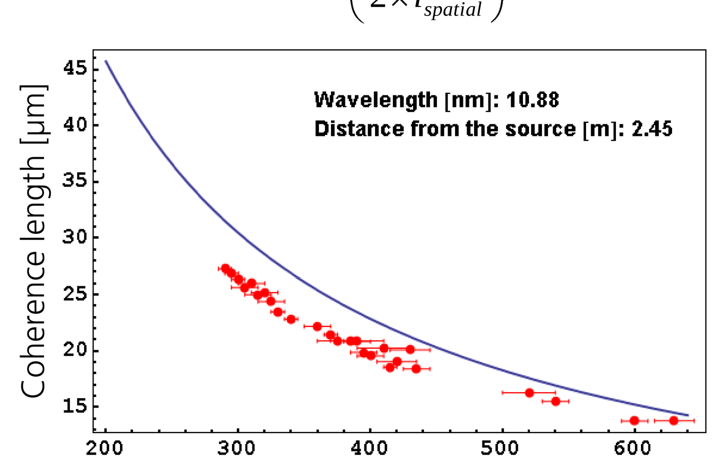




$$V = \frac{I_{Max}(d,Q) - I_{Min}(d,Q)}{I_{Max}(d,Q) + I_{Min}(d,Q)}$$

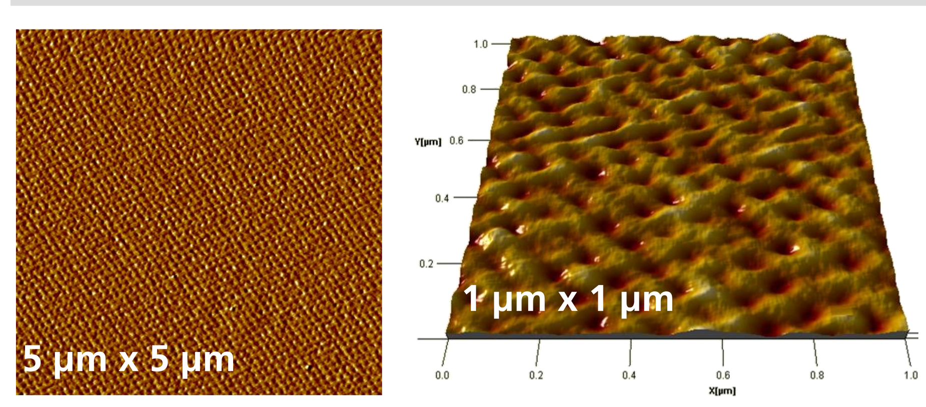
$$V = Exp\left(\frac{d^2}{2\times l^2_{spatial}}\right)$$





Coherence length up to **27 µm** is achievable with a moderate spatial filtering

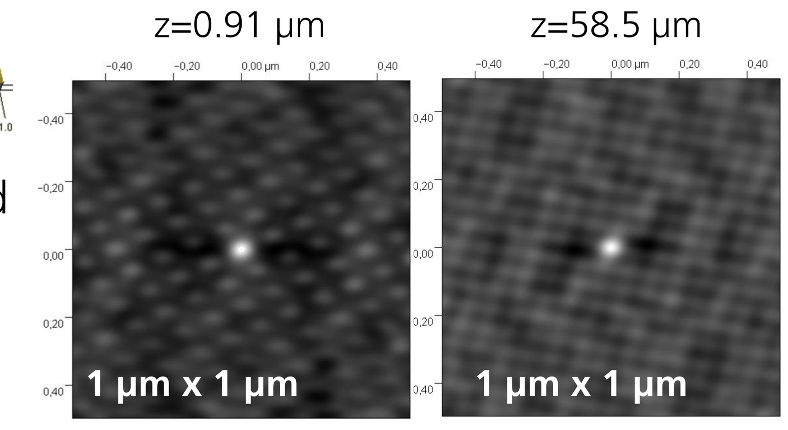
First exposure results



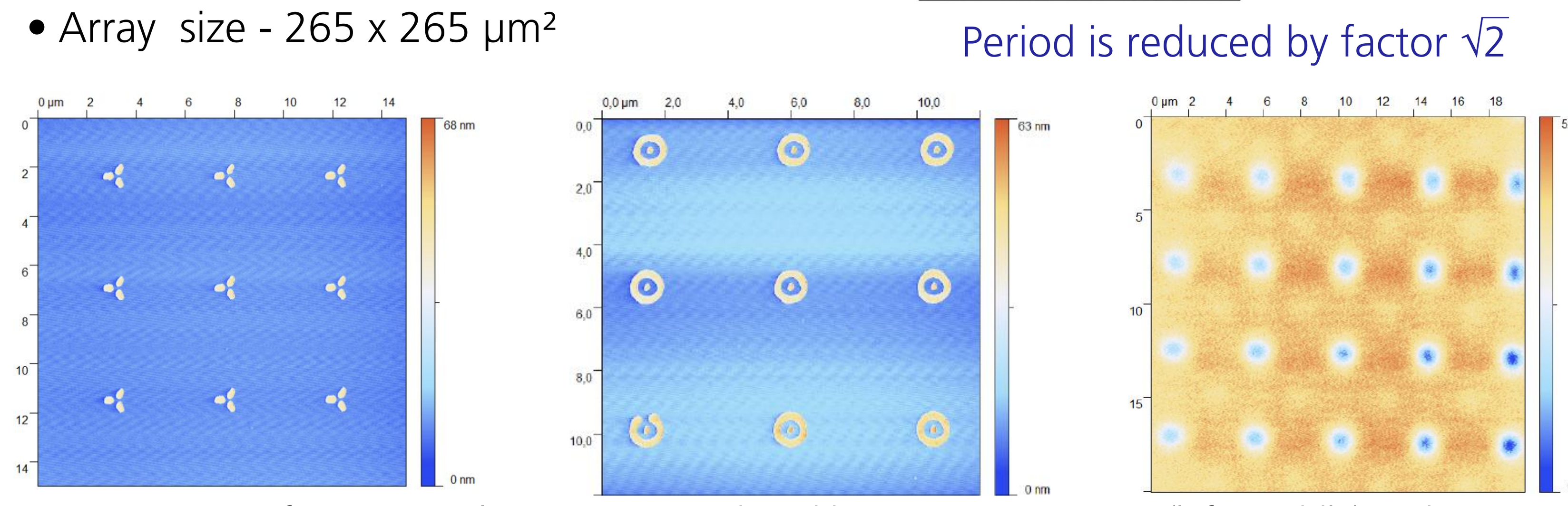
AFM measurements of PMMA resist structured with Nb/Ni pinhole mask in the contact mode.

- Period of structures - 100 nm
- Hole diameter - 40 nm
- Array size - 265 x 265 µm²

2D autocorrelation function of AFM images of PMMA resist, exposed in mono-chromatic (left) and achromatic (right) Talbot modes.



Period is reduced by factor $\sqrt{2}$



Arrays of nanooptical resonators produced by proximity printing (left, middle) and monochromatic Talbot lithography (right)

Summary

- EUV interference lithography with compact sources allows for high throughput patterning with high resolution and has a huge potential for applications
- Emission of gas discharge source was optimised to achieve highest possible intensity within 3.2% bandwidth, spatial coherence of the source measured
- Free standing thin Nb membranes for necessary transmission masks were manufactured with areas exceeding 1 mm^2 and patterned with e-beam
- Proof-of-principle setup for EUV patterning based on compact gas discharge plasma EUV source was designed and realized
- First exposure results confirmed a usability of the achromatic Talbot self imaging for high resolution patterning
- Utilisation of Fresnel diffraction exposure mode enables production of complex nanoresonator arrays

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